SYSTEMATIC REVIEW

Safety and efficacy of Azithromycin in prevention of chronic obstructive pulmonary disease exacerbation: systematic review and meta-analysis. [version 1; referees: awaiting peer review]

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Abstract

Background: Chronic obstructive pulmonary disease (COPD) causes a major burden in terms of deaths and hospitalizations worldwide; it is associated with progressive lung function loss, and frequent exacerbations. Administration of macrolides has been considered beneficial in reducing the frequency of COPD exacerbations. The aim of this study is to assess the safety and efficacy of long-term administration of Azithromycin for patients with chronic obstructive pulmonary disease.

Methods: An extensive search was conducted on SCOPUS, and PubMed databases, CENTRAL, and ClinicalTrials.gov clinical trial registers for randomized clinical trials conducted on COPD patients and administered Azithromycin for more than two weeks. The selected studies underwent assessment for the risk of bias. We conducted random-effect model meta-analysis for the frequency of acute exacerbations during follow-up as a primary outcome.

Results: Out of 1021 screened records, 3 RCTs (Randomized controlled trials) involving 1264 patients were included in the final analysis. The pooled data of all 3 trials showed that administration of Azithromycin reduced the frequency of acute exacerbation of COPD [risk ratio (RR) = 0.69; 95% CI 0.53, 0.91, p = 0.01]. Subgroup analysis indicated that 500 mg Azithromycin [risk ratio (RR) =0.65; 95% CI 0.53-0.79, p=0.01] was found to be more beneficial than 250 mg Azithromycin [risk ratio (RR) = 0.60; 95% CI 0.27-1.33, p=0.21] in reducing acute exacerbation rate, however due to many limitations the analysis of the dosage was not conclusive.

Conclusion: Long-term Azithromycin administration for COPD patients is statistically not associated with increased risk of developing adverse events; in addition, it might be effective in reducing the frequency of acute exacerbations of COPD. However, dosage and duration of Azithromycin administration analysis was not conclusive and thus more RCTs are needed in these areas.

Keywords
chronic obstructive pulmonary disease, acute exacerbation, macrolides, Azithromycin
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Abbreviations
COPD: Chronic obstructive pulmonary disease.
FEV1: Forced expiratory volume in 1 second.
FVC: Forced vital capacity.
RR: Risk ratio.
CI: Confidence interval.
SGRQ: St George Respiratory Questionnaire.
SF-36: Short-form 36 Health Survey.
SF-12: 12-Item Short-Form Health Survey.

Introduction
Chronic obstructive pulmonary disease (COPD) is “a disease state characterized by airflow limitation that is not fully reversible”1. It is a progressive life threatening lung disease, with frequent symptoms that include: chronic cough, breathlessness, and sputum production2. It is the fourth leading cause of death worldwide affecting more than 60 million people and it is estimated to become the third by 2030, 3.2 million deaths occur due to COPD, with 90% of them occurring in middle and low income countries3-5. Until now, there is no definitive treatment for COPD and thus effective management of COPD relies on improving health status, reducing the mortality, as well as preventing and treating complications and exacerbations of the disease6.

COPD exacerbation is defined as “an acute worsening of respiratory symptoms that result in additional therapy”, and classified as mild (responsive to short acting bronchodilators), moderate (requiring antibiotics and/or oral corticosteroids in addition to short acting bronchodilators), or severe (requiring hospitalization)7. Numerous international guidelines have discussed recommendations about the benefits of antimicrobial agents in patients with acute exacerbation of COPD, as they are more prone to develop bacterial infections8-10. Among these antimicrobial agents, macrolides (such as Azithromycin) are especially favored as prophylactic antibiotics in COPD, mostly due to their potentially beneficial anti-inflammatory and immunomodulatory roles, in addition to their known antibacterial effect11.

Azithromycin belongs to macrolides family; it is a semi-synthetic antibiotic derived from another macrolide, erythromycin. Azithromycin has bactericidal and bacteriostatic properties, hence it is used in treating certain bacterial infections12. Azithromycin acts by binding reversibly to the 50S ribosomal subunit of the 70S ribosome of the targeted bacteria, thereby inhibiting the translocation step of protein synthesis stopping bacterial growth13.

Several studies have discussed the beneficial role of macrolides for COPD patients14-19, some of them suggested that long-term Azithromycin therapy has been shown to decrease the rate of recurrence and severity of exacerbations of COPD20-21. However, there is little evidence as to whether Azithromycin is safe and efficacious for management of COPD; thus our study aims to evaluate the efficacy and safety of long-term administration of Azithromycin therapy for chronic obstructive pulmonary disease by accumulating the evidence from randomized control trials that studied the efficacy and safety of Azithromycin administration for COPD patients.

Methods
Search strategy
We systematically searched the literature on PubMed and Scopus databases, as well as the Cochrane central register of controlled trials (CENTRAL) and ClinicalTrials.gov register clinical trial registers. We searched using the terms; chronic obstructive pulmonary disease, exacerbation, chronic bronchitis, emphysema, Azithromycin. The electronic search string used for PubMed was as follows: (((chronic obstructive pulmonary disease OR chronic bronchitis) OR emphysema) AND exacerbation) AND Azithromycin. Our search was limited to human studies only. Our last search was on January 24, 2018. Moreover, hand searching was done by screening the reference lists of all included studies (Figure 1).

Inclusion criteria
Our eligibility criteria for studies to be included in our meta-analysis were: (1) Randomized controlled trials that included only stable COPD patients in any stage of the disease. (2) COPD is defined clinically as [forced expiratory volume in 1 second (FEV1) /forced vital capacity (FVC)] <70%, FEV1 <80% predicted, and an increase in FEV1 <12% (or 200 ml) after inhaling bronchodilators, according to Tiffeneau-Pinelli Index22. (3) Studies that used Azithromycin. (4) The drug was administered orally and the therapy lasted more than two weeks. (5) Information about clinical efficacy or the safety of the drug were reported.

Studies selection
Four reviewers, AA, KA, AA, and HA screened the titles and abstracts of the search results independently for potentially eligible studies. After removing duplicates and irrelevant records, they independently reviewed the full-text of potentially eligible studies using the previously mentioned inclusion criteria. Any differences between the reviewers were solved through consensus. There were no disagreements that needed to be resolved by the senior author.

Data extraction and quality assessment
We measured the risk of bias for all studies that fulfilled our inclusions criteria using RevMan 5.3 software (Cochrane Collaboration, Copenhagen, Denmark) risk of bias assessment tool using: allocation concealment, random sequence generation, blinding of participants and personnel, incomplete outcome data, blinding of outcome assessment, selective reporting as the main parameters for bias. The information that we extracted from the selected studies were study setting information, patients’ characteristics information, treatment information (dosage, therapy strategy, course of therapy, concomitant medication to treat COPD), frequency of exacerbations, and adverse events reports. The reviewers extracted this information independently. Output RevMan file used for analysis is available as Underlying data23.
Statistical analyses

We used random-effects models to pool treatment effects and to calculate the risk ratios (RR) with 95% CI for all clinical end-points, which were the frequencies of exacerbations. All types of exacerbations (mild, moderate, and severe) were included in the pooled analysis with no distinction between them, because some of the included studies reported severe exacerbations while others reported non-severe exacerbations. To examine the robustness of the effect we performed a sensitivity analysis by removing the trials with the highest weights and computing the overall estimates for the remaining studies. Regarding statistical heterogeneity, we used the I² statistic on a scale of 0–100% (>50% indicated a statistical between-study inconsistency, and >75% represented a very large degree of heterogeneity). Subgroup analysis were performed for two strata of data, dosage of Azithromycin used (250 mg Azithromycin or 500 mg Azithromycin) and the duration of the administration (3 months or 12 months). Funnel plot method was used to assess the publication bias. P < 0.05 was considered statistically significant. RevMan 5.3 software (Cochrane Collaboration, Copenhagen, Denmark) was used to perform the pooling analyses of the data.

Results

Studies identification and selection
Initially 1031 published records were identified (677 from SCOPUS, 199 from PubMed, 15 from ClinicalTrials.gov register, and 140 from CENTRAL) (Figure 1). 4 studies...
meet the inclusion criteria. 1348 participants were included in the four trials, the follow-up duration varied among the studies: 3 months\textsuperscript{25}, 6 months\textsuperscript{26}, and 12 months\textsuperscript{24,28}. Of the total number of participants in the included trials, 674 participants were randomly assigned to receive Azithromycin, while 674 were allocated to receive Placebo; in addition both groups continued receiving their concomitant medications (long acting \(\beta_2\) agonists, long acting anticholinergics, inhaled corticosteroids, short acting \(\beta_2\) agonists, oral Prednisolone) (Table 1). Azithromycin dosages used were 250 mg Azithromycin\textsuperscript{24,25,27} and 500 mg Azithromycin\textsuperscript{26}.

The duration of Azithromycin therapy was for 3 months\textsuperscript{25,27} and 12 months\textsuperscript{24,28}, the total number of withdrawals among the selected studies was 66. Three studies\textsuperscript{24,26,27} compared the frequency of acute exacerbation difference that occurred during the follow-up period between the Azithromycin group and the Placebo group using Poisson regression model. One study\textsuperscript{25} reported acute exacerbations as percentages for both of the study groups. All four studies reported the adverse events that occurred during the follow-up period. In addition to acute exacerbations rate and the adverse events, other outcomes like health related quality of life\textsuperscript{24–27}, bacterial culture, macrolides resistance\textsuperscript{24,26,27}, and pulmonary functions test\textsuperscript{24–27} were also reported.

**Qualitative data synthesis**

The time to the first acute exacerbation of COPD in days was higher among patients who received Azithromycin compared patients who received the Placebo\textsuperscript{24–26}. Uzun et al. revealed that hospital admission odds ratio did not differ between the two groups\textsuperscript{26}, however, according to the other studies hospital admissions were reported more amongst the Placebo group\textsuperscript{24,25,27}. Furthermore, chest computed tomography symptom score did not show any difference between the two groups\textsuperscript{27}, and after 12 weeks of Azithromycin therapy a significant increase in the Leicester Cough Questionnaire total score was reported in the Azithromycin group compared with the Placebo. Pulmonary function test was conducted in all four studies\textsuperscript{24–27}, with the exception of Albert et al., all indicated that no significant difference in the test results were reported between Azithromycin and Placebo groups.

Nasopharyngeal colonization was assessed in three studies\textsuperscript{24,26,27}, two of them\textsuperscript{24,26} reported that fewer patients in the Azithromycin group had positive culture during the course of the study (p value < 0.001, p value = 0.044 respectively) while the other\textsuperscript{27} reported no difference between the Azithromycin and Placebo group. Macrolide-resistant bacteria were detected more in the Azithromycin group of Simpson et al., in which the incidence of resistance was 81% among Azithromycin group, and 41% in the placebo (p value < 0.001)\textsuperscript{27}, however it was detected more among the Placebo group with 24%, in contrast to 6% among Azithromycin group (p value = 0.036) from Uzun et al.\textsuperscript{26}. Nasopharyngeal colonization was not associated with the occurrence of acute exacerbations in either group (p value 0.31)\textsuperscript{27}.

Quality of life was recorded using different tools: St George Respiratory Questionnaire (SGRQ)\textsuperscript{24–27}, Short-form 36 Health Survey (SF-36)\textsuperscript{24,25,27}, and the 12-Item Short Form Health Survey (SF-12)\textsuperscript{24}. Three studies\textsuperscript{24–26} reported a decrease in SRGQ total scores in the Azithromycin group compared with the Placebo group, however one study\textsuperscript{27} reported no decrease in the total score among Azithromycin group. The results of the SF-36 scores varies among studies as one study\textsuperscript{24} stated that no changes were seen in the scores while the other study\textsuperscript{25} reported a significant difference in the scores between Azithromycin and Placebo.

**Table 1. characteristics of the included studies.**

<table>
<thead>
<tr>
<th>Literature Source</th>
<th>Total subjects N</th>
<th>Azithromycin group N</th>
<th>Placebo Group N</th>
<th>Males N</th>
<th>Females N</th>
<th>Therapy strategy</th>
<th>Concomitant medications To treat COPD</th>
<th>Course of therapy/month</th>
<th>age mean Yrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albert et al.</td>
<td>1142</td>
<td>570</td>
<td>572</td>
<td>661</td>
<td>456</td>
<td>Azithromycin 250 mg/day compared with placebo</td>
<td>Inhaled glucocorticoids, LAMAs,LABAs</td>
<td>12 months</td>
<td>66 ± 9</td>
</tr>
<tr>
<td>Berkhof et al.</td>
<td>84</td>
<td>42</td>
<td>42</td>
<td>63</td>
<td>21</td>
<td>Azithromycin 250 three times/week compared with placebo</td>
<td>Inhaled glucocorticoids, LAMAs,LABAs</td>
<td>3 months</td>
<td>68 ±10</td>
</tr>
<tr>
<td>Simpson et al.</td>
<td>30</td>
<td>15</td>
<td>15</td>
<td>19</td>
<td>11</td>
<td>Azithromycin 250 mg/day compared with placebo</td>
<td>inhaled corticosteroids</td>
<td>3 months</td>
<td>70.8 ± 7.6</td>
</tr>
<tr>
<td>Uzun et al.</td>
<td>92</td>
<td>47</td>
<td>45</td>
<td>40</td>
<td>52</td>
<td>azithromycin dihydrate 500 mg three times/week compared with placebo</td>
<td>Inhaled glucocorticoids, LAMAs,LABAs</td>
<td>12 months</td>
<td>64.8 ± 10.2</td>
</tr>
</tbody>
</table>

N: number, Yrs: years, COPD: chronic obstructive pulmonary disease, LAMAs: long acting anticholinergics, LABAs: long acting \(\beta_2\) agonists.
groups. In addition, the mean change differed significantly between the Placebo group and the Azithromycin group in the mental component score of SF-12. The most commonly reported adverse event was hearing decrement which was reported in 18% (252) of the participants, an audiogram-confirmed hearing decrement occurred more frequently in participants receiving Azithromycin compared to those receiving Placebo (P=0.04), however, audiogram-confirmed hearing decrement was used in only one study. Table 2 demonstrates the side effects that occurred among the patients.

**Table 2. Adverse events reported among the patients.**

<table>
<thead>
<tr>
<th>Adverse events</th>
<th>Azithromycin group</th>
<th>Placebo group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patients % (n)</td>
<td>Patients % (n)</td>
</tr>
<tr>
<td>Gastrointestinal*</td>
<td>5 (37)</td>
<td>4 (31)</td>
</tr>
<tr>
<td>Cardiovascular #</td>
<td>4 (32)</td>
<td>5 (36)</td>
</tr>
<tr>
<td>Hearing decrement</td>
<td>21 (142)</td>
<td>16 (110)</td>
</tr>
<tr>
<td>Respiratory &amp;</td>
<td>4 (33)</td>
<td>7 (49)</td>
</tr>
<tr>
<td>Others $</td>
<td>25 (174)</td>
<td>26 (178)</td>
</tr>
</tbody>
</table>

* = diarrhea, nausea, vomiting and gastric ulcer...etc.
# = QTc prolongation, myocardial infarction, supraventricular tachycardia, heart failure...etc.
& = common cold, dyspnea and cough, Pneumonia...etc.
$ = Neoplasm, Tinnitus, Allergic reactions, abnormal lab tests...etc.

**Quantitative data synthesis**

The final analysis of the pooled data of the all three trials showed that administration of Azithromycin reduced the frequency of acute exacerbation of COPD [risk ratio (RR) = 0.69; 95% CI 0.53, 0.91, p = 0.008] (Figure 2). Subgroup analysis of Azithromycin dosage (Table 3) revealed that 500 mg Azithromycin [risk ratio (RR) = 0.65; 95% CI 0.53–0.79, p = 0.01] is more beneficial than 250 mg Azithromycin [risk ratio (RR) = 0.60; 95% CI 0.27–1.33, p = 0.21] in reducing acute exacerbation rate. Moreover, administration of Azithromycin for 12 months [risk ratio (RR) = 0.75; 95% CI 0.59–0.94, p = 0.01] was more effective than 3 months. [risk ratio (RR) = 0.36; 95% CI 0.16–0.79, p = 0.01]. Additionally, long-term administration of Azithromycin to COPD patients was not associated with increased risk of developing adverse events [risk ratio (RR) = 0.94; 95% CI 0.81, 1.11, p = 0.48] (Figure 3), subgroup analysis of Azithromycin dosage and therapy duration (Table 4) reported no significant difference between Azithromycin and Placebo groups in developing adverse events.

Regarding the risk of bias assessment, the included studies had low risk of bias. Additionally, sensitivity analysis and publication bias sensitivity analysis on the frequency of acute exacerbation performed by deleting the highest weight trial revealed no significant difference on the results (p value changed to 0.03). In addition, sensitivity analysis on the adverse events performed by deleting the highest weight trials also revealed no significant difference between Azithromycin and Placebo groups in developing adverse events.

**Figure 2.** Forest plot of risk ratios of the frequency of acute exacerbations of chronic obstructive pulmonary disorder (COPD) in patients treated with Azithromycin compared to those who received the placebo. The size of the square is proportional to the weight of the individual studies. M-H = Mantel-Haenszel method.

**Table 3. Subgroup analysis for the frequency of acute exacerbation of chronic obstructive pulmonary disorder (COPD) based on the therapy duration and azithromycin dosage.**

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Acute exacerbation frequency of COPD studies, n</th>
<th>RR (95% CI)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 mg azithromycin</td>
<td>2</td>
<td>0.60 [0.27, 1.33]</td>
<td>0.21</td>
</tr>
<tr>
<td>500 mg azithromycin</td>
<td>1</td>
<td>0.65 [0.53, 0.79]</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>3 months therapy</td>
<td>1</td>
<td>0.36 [0.16, 0.79]</td>
<td>0.01</td>
</tr>
<tr>
<td>12 months therapy</td>
<td>2</td>
<td>0.75 [0.59, 0.94]</td>
<td>0.01</td>
</tr>
</tbody>
</table>
significant difference on the results (p value changed to 0.36). Furthermore, regarding publication bias analysis, funnel plots of both acute exacerbation frequency and adverse events were symmetrical. In regard to heterogeneity among the studies, 77% heterogeneity was found among the frequency of acute exacerbation meta-analysis studies, while 33% was found among adverse events meta-analysis studies.

Discussion

Long-term administration of Azithromycin was associated with reduction in the frequency of acute exacerbation among COPD patients, similar findings have been detected among cystic fibrosis patients\(^1\), however Yao and colleagues deduced that Erythromycin was more effective than Azithromycin in decreasing acute exacerbation frequency\(^2\).

Many studies have investigated the immunomodulatory effects of macrolides, like decreasing the synthesis of pro-inflammatory cytokines in response to viral infections\(^3\), decreasing the hyper-secretion of pro-inflammatory cytokines and chemokines\(^4\), enhancement of phagocytosis function of alveolar macrophages\(^5\), and preserving airway epithelial integrity\(^6\). Moreover, in addition to the immunomodulatory effects, the decrease in airway bacterial colonization in patients receiving Azithromycin might also be linked to the reduction in the systemic inflammation\(^7\) since infections are the most common cause of acute exacerbation\(^8\).

The statistical pooling of the data revealed that 500 mg dose of Azithromycin is superior to 250 mg dose, however this results is not enough to draw a conclusion that it is more beneficial, since there is only one study included in the meta-analysis that used a 500 mg dose with only 92 patients in contrast to 1256 patients that were included in the studies that used a 250 mg dose.

Moreover, In the meta-analysis, no difference was found regarding the development of adverse events between the Azithromycin group and the Placebo group even at 500 mg dose and for 12 months’ therapy duration, in contrast to a previous meta-analysis, which revealed that nonfatal adverse events (gastrointestinal reactions, ototoxicity, rash, and liver injury) were associated with the Placebo group. In addition, hearing decrement occurred more frequently in participants receiving Azithromycin compared to those receiving Placebo, but the improvements in hearing that occurred on repeat testing, suggested that hearing decrements were overestimated in both groups. Gastrointestinal adverse events were the second most common encountered, conversely, they were the most common side effects reported in two previous studies\(^9, 22\) nevertheless, the usage of serial audiometry was only in one study while the other included studies report no usage of audiometry in assessing hearing decrement among the participants, this might have led to underreporting of adverse events in these studies, which may in turn have led eventually to this result in the meta-analysis. Additionally, Albert et al. and Simpson et al. used a daily dose of 250mg Azithromycin, but Berkhof et al. used a three times a week dose of 250mg Azithromycin, while Uzun et al. used a three times a week dose of 500mg Azithromycin. The meta-analysis did not differentiate between intermittent and daily dosing, which might affect the results of the subgroup analysis of dosage and adverse events.

In summary, this study revealed that, long-term Azithromycin administration for COPD patients is not statistically associated with increased risk of developing adverse events, yet three studies did not perform serial audiometry which might have led to under reporting of the adverse events. Furthermore, there is a lack of differentiation between intermittent and daily dosing in the adverse events meta-analysis, these limitations might proscribe such a conclusion. In addition, the results of the pooled data suggest that Azithromycin is effective in reducing the frequency of acute exacerbation of COPD, and the use of Azithromycin may be beneficial for COPD patients. Only four studies were included in this review, more studies are required to confirm our findings especially regarding dosage and adverse events.

Data availability

Underlying data
Harvard Dataverse: Systematic Revman file. [https://doi.org/10.7910/DVN/EQBMC](https://doi.org/10.7910/DVN/EQBMC)

Reporting guidelines
Harvard dataverse, PRISMA checklist for ‘Safety and efficacy of Azithromycin in prevention of chronic obstructive pulmonary disease exacerbation: systematic review and meta-analysis’. [https://doi.org/10.7910/DVN/3XMNF](https://doi.org/10.7910/DVN/3XMNF)
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References

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